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TECHNICAL REPORT 4975

SENSITIVITY OF CASED CHARGES OF MOLTEN AND SOLID COMPOSITION B TO IMPACT BY PRIMARY STEEL FRAGMENTS

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JUNE 1976

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DOVER, NEW JERSEY

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Cased Comp B acceptors-molten/solid
High velocity steel fragments
Minimum fragment velocity for detonation
Maximum fragment velocity without detonation
Sensitivity to impact-molten/solid Comp B
Fragment velocity
Steel acceptor plate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experimental program was conducted to establish the sensitivity of cased charges of Composition B, in the molten and solid state, to impact by high velocity steel fragments. Primary fragments having a square cross-sectional area and weighing 0.5, 1.0 and 2.0 ounces were propelled at targets by explosive means. Velocity levels were varied between 3,000 and 7,000 fps in order to determine the threshold velocity range required for a detonation.

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20. Abstract (Continued)

Results of this program indicate that molten Composition B charges are significantly more sensitive to impact than solid charges. In addition, it appears that a relationship exists between the kinetic energy of the fragment, its impact area and the threshold detonation velocity.

The following metric conversions, which conform to ASTM Standard E-380-74 Metric Practice Guide, are provided for the readers convenience.

Page No.	U. S.	Metric
1,3,10-15	0.5 oz.	14.175g
1,11,12,14,15	1.0 oz.	28.349g
1,3,12-15	2.0 oz.	56.698g
1,4,9-15	.125 in.	3.175×10^{-3}m
1,4,5,9-15	.375 in.	9.525×10^{-3}m
1,4-6,10,13,15	3.0 in.	7.620×10^{-2}m
1,11,13	5,798 Fps	1,767.230 m/sec
1,11	5,418 Fps	1,651.406 m/sec
1,12,13	4,339 Fps	1,322.527 m/sec
1,11	5,828 Fps	1,776.374 m/sec
1,11	5,155 Fps	1,571.244 m/sec
1,12	4,090 Fps	1,246.632 m/sec
1,12	3,166 Fps	964.997 m/sec
1,11	7,047 Fps	2,147.926 m/sec
1,11	3,587 Fps	1,093.318 m/sec
1,11	5,206 Fps	1,586.789 m/sec
1,11	4,518 Fps	1,377.086 m/sec
1,12	4,436 Fps	1,352.093 m/sec
1,10,11,14,15	7,068 Fps	2,154.326 m/sec
1,11	5,150 Fps	1,569.720 m/sec
1,12	4,357 Fps	1,328.013 m/sec
1,11	4,626 Fps	1,410.005 m/sec
1,12	4,292 Fps	1,308.201 m/sec
1,12	2,937 Fps	895.198 m/sec

Page No.	U. S.	Metric
1,11	4,602 Fps	1,402.689 m/sec
1,12	3,271 Fps	997.000 m/sec
1,12,14	4,510 Fps	1,374.648 m/sec
1,30	0.25 oz.	7.087g
1,15	4,304 Fps	1,311.859 m/sec
1,15	6,136 Fps	1,870.253 m/sec
1,15	4,505 Fps	1,373.124 m/sec
3	6,000 Fps	1,828.8 m/sec
4,10,11	.250 in.	6.35×10^{-3}m
4,9	1.00 in.	2.54×10^{-2}m
4,5,7,9	2.00 in.	5.08×10^{-2}m
4	7.25 in.	1.842×10^{-1}m
4	8.50 in.	2.159×10^{-1}m
4	.75 in.	1.905×10^{-2}m
4,5,6,9	8.00 in.	2.032×10^{-1}m
4	1.25 in.	3.175×10^{-2}m
4,5	400 Ft.	121.92 m
4	1.50 in.	3.81×10^{-2}m
4	1.75 in.	4.445×10^{-2}m
4,5,6,8,9	6 in.	1.524×10^{-1}m
4,6	.035 in.	8.89×10^{-4}m
5	5 in.	1.27×10^{-1}m
5	6 Ft.	1.829 m
5	3/8 in.	9.525×10^{-3}m

Page No.	U. S.	Metric
5	1/8 in.	3.175×10^{-3}m
6	1-3/4 in.	4.445×10^{-2}m
6	90 Ft.	27.432 m
7	24 in.	6.096×10^{-1}m
7	14 in.	3.556×10^{-1}m
7	4 in.	1.016×10^{-1}m
7,13	4000 Fps	1,219.2 m/sec
7	84 in.	2.134 m
7	242 Fps	73.762 m/sec
10,13	.540 in.	1.372×10^{-2}m
10	0.040 in.	1.016×10^{-3}m
10	4,748 Fps	1,447.190 m/sec
10,13	4,578 Fps	1,395.374 m/sec
10	4,742 Fps	1,445.362 m/sec
10	164 Fps	49.987 m/sec
10,11,13	.930 in.	2.362×10^{-2}m
11	4,291 Fps	1,307.897 m/sec
11	4,495 Fps	1,370.076 m/sec
12	202 Fps	61.570 m/sec
12	97 Fps	29.566 m/sec
12	500 Fps	152.4 m/sec

Page No.	U. S.	Metric
13	7,000 Fps	2,133.6 m/sec
13	.380 in.	9.652×10^{-3}m
13	1.68 oz/in.^{2}	7.383 g/cm^2
13	239 Fps	72.847 m/sec
13	.58 oz/in.^{2}	2.549 g/cm^2
13	1,220 Fps	371.856 m/sec

For Figures 8, 12, 13 and 14 the following conversion factors are to be used:

	Multiply by	
Fps	3.048×10^{-1}	m/sec
in.	2.540×10^{-2}	m
oz.	28.349	g
oz./in.^{2}	4.3945	g/cm^2

43	.5 oz.	14.175 g
	1.0 oz.	28.349 g
	1.5 oz.	42.524 g
	2.0 oz.	56.698 g
	.930 in.	2.362×10^{-2}m
	.380 in.	9.652×10^{-3}m
	.250 in.	6.35×10^{-3}m
	.540 in.	1.372×10^{-2}m
	1.09 in.	2.769×10^{-2}m
	3 in.	7.62×10^{-2}m

Page No.	U. S.	Metric
43,47-49	0.125 in.	3.175×10^{-3}m
43,47,48	1000 Fps	304.8 m/sec
43,47,48	2000 Fps	609.6 m/sec
43,47,48	3000 Fps	914.4 m/sec
43,47,48	4000 Fps	1,219.2 m/sec
43,47,48	5000 Fps	1,524.0 m/sec
43,47,48	6000 Fps	1,828.8 m/sec
43,49	7000 Fps	2,133.6 m/sec
47-49	.5 oz./in.^{2}	2.197 g/cm^2
47-49	1.0 oz/in.^{2}	4.3945 g/cm^2
47-49	1.5 oz./in.^{2}	6.592 g/cm^2
47-49	2.0 oz./in.^{2}	8.789 g/cm^2

For Tables 1 - 11 the following conversion factors are to be used:

	Multiply by	
oz.	2.834×10^{-2}	Kg
in.	2.540×10^{-2}	m
oz./in.^{2}	4.3945	g/cm^2
Fps	3.048×10^{-1}	m/sec

19,33	.25 oz.	7.087 g
19-24,31-33	.5 oz.	14.175 g
19,25-28,31-33	1.0 oz.	28.349 g
19,29-33	2.0 oz.	56.698 g

Page No.	U. S.	Metric
19-27,27-32	.125 in.	3.175×10^{-3}m
19-24,26,27-33	.375 in.	9.525×10^{-3}m
19-21	.540 in.	1.372×10^{-2}m
19,22-28,33	.930 in.	2.362×10^{-2}m
19,20,22,25,29,33	.250 in.	6.35×10^{-3}m
19,29,30,33	1.09 in.	2.769×10^{-2}m
19	1.79 oz./in.^{2}	7.866 g/cm^2
19,31	1.68 oz./in.^{2}	7.383 g/cm^2
19,31	0.58 oz./in.^{2}	2.549 g/cm^2
19,31	1.16 oz./in.^{2}	5.100 g/cm^2
20,21,25	8 in x 8 in x 1 in	2.032×10^{-1}m x 2.032×10^{-1}m x 2.54×10^{-2}m
20,24,27	8 in x 8 in x .75 in.	2.032×10^{-1}m x 2.032×10^{-1}m x 1.905×10^{-2}m
20,21,25-30	.040 in.	1.016×10^{-3}m
20,22,24,25,27-30	1.000 in.	2.540×10^{-2}m
20	1.875 in.	4.763×10^{-2}m
20,25-30	.500 in.	1.27×10^{-2}m
20,21	.065 in.	1.651×10^{-3}m
20,33	4,055 Fps	1,235.964 m/sec
20	2,575 Fps	784.86 m/sec
20	1,704 Fps	519.379 m/sec
20	8,209 Fps	2,502.103 m/sec
20	3,196 Fps	974.141 m/sec
20	3,545 Fps	1,080.516 m/sec
20	3,716 Fps	1,132.637 m/sec

Page No.	U. S.	Metric
20,33	3,959 Fps	1,206.703 m/sec
20	3,984 Fps	1,214.323 m/sec
20	3,937 Fps	1,199.998 m/sec
20	4,472 Fps	1,363.066 m/sec
20	3,948 Fps	1,203.350 m/sec
21-23,25,26,29	6 in x 6 in x 2 in	1.524×10^{-1}m x 1.524×10^{-1}m x 5.08×10^{-2}m
21,31,32	3 in.	7.62×10^{-2}m
21,31	4,742 Fps	1,445.362 m/sec
21,31	4,578 Fps	1,395.374 m/sec
21	4,748 Fps	1,447.190 m/sec
21	4,534 Fps	1,381.963 m/sec
21	4 in	1.016×10^{-1}m
21	5 in	1.27×10^{-1}m
21	6 in	1.524×10^{-1}m
21	8 in	2.032×10^{-1}m
22,25,29	.038 in.	9.652×10^{-4}m
22-25,27,30	.750 in.	1.905×10^{-2}m
22	1.500 in.	3.81×10^{-2}m
22	4 in x 4 in x 4.5 in	1.016×10^{-1}m x 1.016×10^{-1}m x 1.143×10^{-1}m
22	8,834 Fps	2,692.603 m/sec
22	8,530 Fps	2,599.944 m/sec
22	8,053 Fps	2,454.554 m/sec
22	6,508 Fps	1.983.638 m/sec
22	5,651 Fps	1,722.425 m/sec
22	4,479 Fps	1,365.199 m/sec

Page No.	U. S.	Metric
22,31,32	5,798 Fps	1,767.230 m/sec
22	3,909 Fps	1,191.463 m/sec
22	5,102 Fps	1,555.090 m/sec
22,31,32	5,206 Fps	1,586.789 m/sec
23	5,725 Fps	1,744.98 m/sec
23,31-33	7,068 Fps	2,154.326 m/sec
23	9,462 Fps	2,884.018 m/sec
24,27,28	1.25 in.	3.175×10^{-2}m
24	.625 in.	1.588×10^{-2}m
24,27,28,30	6 in x 6 in x 1.75 in.	1.524×10^{-1}m x 1.524×10^{-1}m x 4.445×10^{-2}m
24	5.645 Fps	1,720.596 m/sec
24	6,630 Fps	2,020.824 m/sec
24	4,945 Fps	1,507.236 m/sec
24	5,064 Fps	1,543.507 m/sec
24,31,32	5,155 Fps	1,571.244 m/sec
24,31,32	4,626 Fps	1,410.005 m/sec
24,31,32	7,047 Fps	2,147.926 m/sec
24	7,516 Fps	2,290.877 m/sec
24,31,32	4,602 Fps	1,402.690 m/sec
25	5,988 Fps	1,825.142 m/sec
25	5,893 Fps	1,796.186 m/sec
25	6,102 Fps	1,859,890 m/sec
25,33	6,136 Fps	1,870.253 m/sec

Page No.	U. S.	Metric
25,31,32	5,418 Fps	1,651.406 m/sec
25	4,291 Fps	1,307.897 m/sec
25	3,683 Fps	1,122.578 m/sec
25	2,704 Fps	824.179 m/sec
25	2,818 Fps	858.926 m/sec
25	3,745 Fps	1,141.476 m/sec
25	4,495 Fps	1,370.076 m/sec
26	6 in x 6 in x 1.5 in	1.524×10^{-1}m x 1.524×10^{-1}m x 3.81×10^{-2}m
26,31,32	4,518 Fps	1,377.086 m/sec
26,31,32	5,828 Fps	1,776.374 m/sec
26,31,32	5,150 Fps	1,569.72 m/sec
27	4,602 Fps	1,402.690 m/sec
27	5,231 Fps	1,594.409 m/sec
27	4,967 Fps	1,513.942 m/sec
27	3,741 Fps	1,140.257 m/sec
27	4,500 Fps	1,371.6 m/sec
27,31,32	4,090 Fps	1,246.632 m/sec
27	3,464 Fps	1,055.827 m/sec
27	3,282 Fps	1,000.354 m/sec
27,31,32	4,292 Fps	1,308.202 m/sec
27	5,853 Fps	1,783.994 m/sec
27	5,295 Fps	1,613.916 m/sec
27	5,090 Fps	1,551.432 m/sec

Page No.	U. S.	Metric
28	4,666 Fps	1,422.197 m/sec
28,31,32	3,587 Fps	1,093.318 m/sec
28,31,32	3,271 Fps	997.001 m/sec
29	6 in. x 6 in. x 2.25 in.	1.524×10^{-1}m x 1.524×10^{-1}m x 5.715×10^{-2}m
29,31,32	4,436 Fps	1,352.093 m/sec
29	4,452 Fps	1,356.970 m/sec
29	2,834 Fps	863.803 m/sec
29	3,553 Fps	1,082.954 m/sec
29	3,984 Fps	1,214.323 m/sec
29,31,32	4,339 Fps	1,322.527 m/sec
29	4,372 Fps	1,332.586 m/sec
29,31,32	4,357 Fps	1,328.014 m/sec
29	4,334 Fps	1,321.003 m/sec
30	.875 in.	2.222×10^{-2}m
30	4,464 Fps	1,360.627 m/sec
30	3,305 Fps	1,007.364 m/sec
30-32	3,166 Fps	964.997 m/sec
30	2,771 Fps	844.6008 m/sec
30-32	2,937 Fps	895.198 m/sec
30-32	4,510 Fps	1,374.648 m/sec
30,33	4,505 Fps	1,373.124 m/sec
33	4,304 Fps	1,311.859 m/sec

PREFACE

The fragment impact experiments reported on in this program are modeled after work presented in Arthur D. Little, Inc. report No. 64514 entitled, "An Experimental Program to Determine the Sensitivity of Explosive Materials to Impact by Regular Fragments," dated December 29, 1965 by McLean and Allan. This previous work studied the sensitivity of both cased and uncased solid charges of Pentolite and Cyclotol to impact by steel fragments. Mr. Richard M. Rindner was Project Engineer on the program and was responsible for the continuation of the present effort. Other personnel that contributed to the program were Mr. William Seals, Picatinny Arsenal and Messr. Howard Gibson and Harry McClary of Hazards Research Corporation.

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SUMMARY

An experimental program has been performed to establish the sensitivity of molten and solid Composition B to impact by non-spinning, primary steel fragments weighing 0.5 to 2.0 ounces and traveling at velocities up to 7,000 fps. Parameters that were varied included acceptor plate thickness, fragment mass per unit impact area and the molten vs. solid physical state of the Composition B. The following table summarizes the results of this program:

Summary of fragment impact test results

Frag wt (oz)	Acceptor plate thk (in.)	Min vel for detonation Solid (fps)	Min vel for detonation Molten (fps)	Max vel without detonation Solid (fps)	Max vel without detonation Molten (fps)
0.5	0.125	5,798	5,155	5,206	4,626
1.0	0.125	5,418	4,090	4,518	4,292
2.0	0.125	4,339	3,166	4,436	2,937
0.5	0.375	*	7,047	≥ 7,068	4,602
1.0	0.375	5,828	3,587	5,150	3,271
2.0	0.375	-	-	≥ 4,357**	≥ 4,510**

* Could not achieve det. level without frag. break-up
** Max. vel. attainable with 3 in. dia. x 3 in. long booster

The explosive launching technique used on this program propelled 0.25, 0.50, 1.0 and 2.0 ounce steel fragments at maximum velocities of 4,304, 7,068, 6,136 and 4,505 fps respectively. Molten Composition B was found to be significantly more sensitive to fragment impact than solid Composition B. Test results indicate that the minimum fragment velocity required for detonation increases as the thickness of the cover plate increases and that threshold initiation velocities are inversely proportional to fragment mass per unit impact area. Finally, it is concluded that an empirical relationship has been established between fragment mass per unit impact area and boundary velocity for most of the cases investigated. Work conducted by previous investigators (Ref 1 and 2) has been extended to allow for the effects of impact area on boundary velocity.

It is recommended that the data generated on this program be used to modify the mathematical equation for boundary velocity presented in References 1 and 2, by applying the effect of fragment mass per unit impact area on boundary velocity. Consideration

should be given to the application of this explosive launch technique as a means of classifying the relative sensitivities of explosives, propellants and pyrotechnic materials to high velocity fragment impact.

INTRODUCTION

This report summarizes the results of a series of experiments performed by Hazards Research Corporation, Denville, New Jersey under the technical direction of the Modernization and Special Technology Division, of the Manufacturing Technology Directorate, Picatinny Arsenal, Dover, New Jersey. The work was funded under Contract No. DAAA21-73-C-0772.

The objective of this program was to investigate the sensitivity of molten and solid Composition B to impact by non-spinning, primary steel fragments weighing 0.5 to 2.0 ounces and traveling at velocities up to 6,000 fps. Primary fragments are defined as those fragments that result from break-up of an explosive casing in the event of a detonation. Usually, these fragments are characterized by having high velocity (several thousand fps) and are comparatively small in size. Variables studied included acceptor plate thickness, fragment mass per unit area, and the molten vs. solid physical state of the Composition B. Results were analyzed by comparing minimum velocities for detonation to maximum velocities without detonation. An attempt was made to establish a relationship between fragment mass per unit frontal area and threshold detonation velocity. Information derived from this program will be used to develop a mathematical model which can be used to predict the boundary velocity of high velocity fragments, with variable mass per unit frontal areas, impacting cased explosive charges that have variable thickness cover plates. The mathematical model will then be applied in the design of new explosive facilities, modernization of existing facilities and in any operations where it is desired to limit the effects of accidental detonations. The net result of this effort will be increased safety at explosive facilities and cost reductions through efficient, knowledgeable design.

EXPERIMENTAL PROGRAM

Materials

The following materials were supplied by Picatinny Arsenal for use in this test program:

(1) Composition B, cast, cylindrical booster, 3.000 in. ± 0.250 in. diameter x 1.000 in. ± 0.250 in. long, Lot HOL-050-54

(2) Composition B, cast, cylindrical booster, 3.000 in. ± 0.250 in. diameter x 2.000 in. ± 0.250 in. long, Lot HOL-050-54

(3) Composition B, cast, cylindrical acceptor, 7.250 to 8.500 in. diameter x 0.750 in. ± 0.250 in. long, Lot HOL-050-54

(4) Composition B, cast, square acceptor, 8.000 in. x 8.000 in. ± 0.250 in. x 0.750 to 1.250 in. thick, Lot HOL-050-54

Hazards Research Corporation furnished the following materials:

(1) High Speed, B & W Reversal Film Type 2962, 16 mm x 400 ft. rolls, mfg. by GAF Corporation

(2) E-83 blasting caps

(3) Tetryl booster, 50 grams, 1.5 in. diameter x 1.0 in. long

(4) Wooden test stands

(5) Lucite buffer plates

(6) Steel fragments, type 1020 H.R.

(7) Steel surrounds, type 1020 H.R.

(8) Steel acceptor plates, type 1020 H.R., 0.125 in. and 0.375 in. thk. x 8 in. square

(9) Steel witness plates, type 1020 H.R., 0.375 in. thk. x 8 in. square

(10) Steel pans, 1.75 in. high x 6 in. square x 0.035 in. thk.

Equipment

Hazards Research Corporation supplied the following high speed camera system:

(1) Model 16-51 NOVA high speed camera with 400 to 20,000 picture per sec prism

(2) Model 16-301, 400 ft. film magazine

(3) Model 16-321 A balanced film spools, 400 ft. capacity

(4) Model 1002 rectifier power supply, 120 volt AC, 60 cycle input with 140 to 150 volts DC to camera

(5) Elgeet 6 inch, f: 3. 8 lens

(6) Model 2001 event timer

(7) Model X-L exposure meter, 100 to 39,000 frames per sec, ASA 50 to 1600

(8) Model 1005 timing light generator, 10, 100, 1000 pulses per sec. output

Description of Experiments

All experiments performed during this program were conducted using the experimental set-up shown pictorially in Figure 1 and schematically in Figure 2. The booster charge was composed of an E-83 cap, 50 gms of Tetryl and a 3 inch diameter by 3 inch long, Composition B charge. This entire explosive train was placed on top of a 5 inch by 5 inch square of Lucite of varying thickness. Glued to the opposite side of the Lucite was a square steel fragment of desired thickness and frontal area as shown in Figure 3. The fragment was surrounded by 4 pieces of equal thickness steel which prevent deformation at the edges of the fragment during the initial stages of launch. Figure 4 is a sketch which depicts the relative positions of the booster, Lucite, fragment and the surround. Figure 5 is a photo of the booster.

The entire fragment propulsion system was supported by a wooden stand that maintained a 6 foot distance between the booster and the acceptor (target). There were two types of targets used on this program, solid and molten Composition B. Each type had a 3/8 inch thick by 8 inches square witness plate on the underside of the charge. The cover plates were either 1/8 inch thick or 3/8 inch thick as required by the experiment. Solid charges were 6 inches square and averaged 2 inches in thickness. When

sandwiched between the cover plate and the witness plate, the sides of the solid charges were bare (See Figure 6). Molten charges were contained by 6 inch square by 1 3/4 inch high steel pans with 0.035 inch thick side walls. Figure 7 is a photo of a molten acceptor with witness and cover plates in place.

A typical test sequence started with the selection of; (a) the fragment velocity desired, (b) Lucite thickness required to attain that velocity, (c) cover plate thickness and (d) physical state of the acceptor charge (molten or solid). The booster charge was then placed on top of the stand, the fragment aimed at the center of the acceptor charge below, the cap armed and the event fired remotely by the high speed camera system. The camera was set-up 90 feet away from the detonation site. Nominal camera speed was 20,000 pictures per second. The high speed camera was the only instrumentation used to record fragment velocity. Tests were valid only when film coverage was acceptable and the fragment impacted on the target area.

Description of Experimental Methods

Fragment Aiming Procedure

Figure 8 depicts the technique used to aim the fragment at the center of the receiver charge. The receiver is placed into position at the bottom of the test stand where it is leveled in two horizontal planes. An 8 inch square steel plate is then placed on top of the plywood platform. The plate has three equi-length plumb bobs suspended from three points 60 degrees apart. The plywood platform is adjusted in two horizontal planes until the tip of each plumb bob is exactly the same distance away from the acceptor cover plate. When this is accomplished the plate is removed and the booster charge is placed into position on the plywood platform. The blasting cap is then connected to the firing circuit and the test set-up is ready to be fired by the camera.

Fragment Calibration Firings

A series of fragment calibration firings were performed to determine the variation of fragment velocity as a function of Lucite spacer thickness. Figure 9 presents the results of these firings and provides a ready reference for the various fragment velocities attainable with a 3 inch diameter by 3 inch long Composition B booster.

Fragment Velocity Measurement

The Nova high speed camera was used to record fragment velocity. It photographed the last 24 inches of fragment travel, including fragment impact. The last 14 inches of flight were marked off in 2 inch increments on the 2 x 4 in. vertical test stand support. Fragment velocity was computed in two ways. The first technique was to determine the elapsed time of fragment travel between the graduated 2 inch markings. Velocity was then computed by dividing the distance traversed by the time it took to traverse that distance. The second technique involved taking the starting time as that frame which was overexposed due to initiation of the booster. Impact at the steel cover plate marked the end of the event. Therefore, with the distance from the face of the fragment to the top of the acceptor plate known, the average velocity was calculated by dividing this distance by the elapsed time. Initial comparisons of the two techniques revealed that at the 4000 fps velocity level there was no significant difference in calculated velocities.

The advantage of the second technique is that lighting of the target area is not critical since initiation of the donor always overexposes the film and impact always results in a columnated beam of light emanating from the steel plate at impact. If impact results in a high order detonation, the detonation occurs within one frame. Since each frame is equal to 50 microseconds (at 20,000 frames per second) the detonation overexposes the film and obliterates the light given off by the columnation effect. Therefore, the high speed camera acts as a timer which is started and stopped by the light given off at initiation and impact.

As fragment velocities exceeded 4000 fps, errors were introduced using the first technique due to blurring of the pictures of the fragment in - flight. It was found that the second technique provided more accurate velocity data and it was decided that all velocity data reported would be that data generated using the second technique.

It should be noted that since the camera photographs in 50 microsecond increments there is a slight error introduced in the time function. Initiation and impact each occur somewhere within a 50 microsecond time frame. Therefore, the time recorded could be up to 100 microseconds too long. At 4000 fps, over the 84 inch flight path, an error of up to 242 fps could result. It was decided that for the purposes of this program, this was not a large experimental error and it was deemed acceptable.

Preparation of Molten Composition B Targets

Molten Composition B acceptors were prepared by placing the steel cover plate, empty 6 inch square steel pan and witness plate into an oven which was maintained at 130°C. Solid chunks of Composition B were placed into a stainless steel pitcher which was also placed inside of the oven. Average soak time in the oven was 12 hours.

Prior to performing the first experiment, a series of dry runs were performed to determine the cooling rate of the acceptor with its hot steel plates in position. It was determined that no solidification occurred within a 3 minute period. All experiments were performed within this time frame.

The last operation performed during this portion of the program was the placing of the hot witness plate and empty steel pan into position on the test stand and the pouring of the molten Composition B into the pan. Prior to pouring, the molten material was stirred in the steel pitcher. This stirring action was necessary to allow the RDX crystals to be suspended uniformly throughout the mixture. Settling time for the bulk of the RDX crystals was greater than the 3 minutes allowed for solidification. Therefore, settling was not considered to be a problem. The Composition B was poured into the pan until it overflowed slightly. This eliminated the entrainment of air between the top plate and the molten surface. After placement of the hot, steel cover plate in position, the cap was armed and fired.

Characterization of Results of Fragment Impact

Impact of high velocity steel fragments on steel cased solid and molten Composition B acceptors resulted in one of the following: no reaction, deflagration or detonation.

No Reaction

This result was characterized by a hole in the flat cover plate, fragmented solid Composition B strewn all over the floor of the test cell (solid acceptor), droplets of solidified explosive on the floor and in the intact steel pan (molten acceptor), and a flat witness plate with a slight dent in it. Surrounds and the steel fragment were always recovered after this type of result occurred. Figure 10 is a post-run photo of a typical witness plate, cover plate and fragment after a no reaction or negative test.

Deflagration

Deflagrations were accompanied by clouds of smoke billowing out of the test cell and the recovery of all steel items in the condition previously described in item (a). No physical evidence of the Composition B remained after a deflagration.

Detonation

Detonations of both a low and high order class were considered to be positive results on this program. Low order detonations were characterized by the fracturing of the acceptor cover plate into 2 or more distorted pieces and the severe bowing of the witness plate. Bowing of 2 or more inches at the center of the plate was common. Some plates were bowed into crudely shaped hemispheres. Figure 11 is a photo which depicts the post-run condition of the steel plates after a low order detonation.

A high order detonation resulted in the complete shrapnellization of the cover plate. In addition, the witness shape plate was always driven downward into its wooden support. Its physical appearance was the mirror image of the explosive charge which rested on it. For example, during the molten Composition B tests the 6 in. x 6 in. pans rested on the 8 in. x 8 in. steel witness plates. After a high order detonation, a bowed 6 in. x 6 in. witness plate would be found with 1 inch wide strips clearly sheared off around its outside edge. Figure 12 is a photo which shows this typical post-run result.

Experimental Results

A total of 85 primary steel fragment impact experiments were performed on this program. Table 1 presents the combinations of parameters tested and the number of experiments performed on each combination. It is seen that 54 tests were performed on solid Composition B acceptors while 31 tests were performed on molten Composition B acceptors. All tests were conducted with steel cover plates either 0.125 in. thick or 0.375 in. thick. Tables 2 through 8 contain the detailed results of each test. A comparison of minimum velocity for detonation and maximum velocity without detonation for all combinations of parameters tested is presented in Table 9. Table 10 provides a summary of test program results. It allows a ready comparison of impact sensitivity for molten and solid Composition B acceptors for the two cover plate thicknesses tested. Figures 13, 14 and 15 graphically present the data contained in Table 9.

Solid Composition B Acceptor - 0.5 Ounce Fragment

Steel Fragment Dimensions - 0.375 in. x 0.540 in. x 0.540 in.

A series of 16 experiments were performed using a 0.375 in. x 0.540 in. x 0.540 in. fragment which weighed 0.5 ounces. Results of these tests are presented in Table 2. The first 3 tests were calibration firings performed without an explosive acceptor. All succeeding tests had solid Composition B acceptors. Tests 5 through 9 failed to yield a detonation at the minimum Lucite thickness of 0.040 in. using the 3 in. diameter x 3 in. long Composition B booster.

In an attempt to achieve higher fragment velocities, the length of the booster was varied in firings 10 through 15. No reproducible, significant increase in fragment velocity resulted by increasing the length beyond 3 inches. The reason for this phenomena is that for a cylindrical charge of finite diameter, the strength of the detonation wave does not increase after a specific distance of travel. The limiting strength is reached when the losses from the sides of the wave become equal to the energy being added by the reaction of additional mass. This condition was generally achieved in our tests when the length of the charge was equal to its diameter, i.e. $l/d = 1$.

The minimum velocity for detonation with this 0.5 ounce fragment was 4,578 fps and the maximum velocity without detonation was 4,742 fps. It is noted that the maximum velocity without detonation is 164 fps higher than the minimum velocity for detonation. This difference is within the acknowledged limits of experimental error on this program.

Steel Fragment Dimensions - 0.125 in. x 0.930 in. x 0.930 in.

As a result of the inability to propel the 0.54 in. square fragment above the 4,748 fps level, it was decided to decrease its thickness and increase its frontal area. A new fragment was fabricated which was 0.125 in. thick x 0.930 in. square. This fragment presented 3 times as much surface area to the Composition B booster thereby increasing its launch velocity.

Results of the 13 tests performed with this fragment and solid acceptors are presented in Table 3. Cover plate thickness was 0.125 in. for 10 tests and 0.375 in. for the remaining 3 tests. It is seen that the thinner fragment was more sensitive to fragment break-up than its predecessor. Test numbers 17, 18, 19 and 29 resulted in fragment break-up. Consequently, these data points were not included in the data analysis. However, lucite thicknesses above 0.250 in. allowed the fragment to stay together and achieve velocities as high as 7,068 fps.

Tests with this 0.5 ounce fragment resulted in a minimum velocity for detonation of 5,798 fps and a maximum velocity without detonation of 5,206 fps for the 0.125 in. thick acceptor plates. No detonations could be achieved using the 0.375 in. acceptor plates. The maximum velocity without detonation for 0.375 in. acceptor plates is therefore, greater than 7,068 fps.

Molten Composition B Acceptor - 0.5 Ounce Fragment

A series of 9 experiments were performed using the 0.125 in. x 0.930 in. square, 0.5 ounce fragment. Table 4 contains the results of these experiments which were performed using solid acceptors. Acceptor plate thickness was 0.125 in. in 6 experiments and 0.375 in. for the remainder. In the case of the former, minimum velocity for detonation was 5,155 fps while maximum velocity without detonation was 4,626 fps. For the thicker plates the spread between the two velocity thresholds was greater due to the lack of sufficient test data. The minimum velocity for detonation was 7,047 fps while the maximum velocity without detonation was 4,602 fps. It is apparent that more tests should be performed using the 0.375 in. thick plates.

Solid Composition B Acceptor - 1.0 Ounce Fragment

Table 5 presents the results of 14 tests performed on this phase of the program. All but 2 of these tests had 0.125 in. thick acceptor plates. Runs 51 and 52 used 0.375 in. thick steel plates. For the thinner acceptor plates the minimum velocity for detonation was 5,418 fps and the maximum velocity without detonation was 4,518 fps. It should be noted that test number 44 yielded a detonation at 4,291 fps. This test was repeated twice (using the same thickness of Lucite) via tests 49 and 50 and resulted in fragment velocities of 4,495 and 4,518 fps with a deflagration and no reaction respectively. It is posited that the fragment fired in test number 44 impacted on its thin edge. For equal velocities, a 1.0 ounce fragment that impacts on its thin edge (0.250 in. x 0.930 in.) delivers 7.5 times as much energy as planar impact of the 0.930 in. square surface. Therefore, results of firing number 44 were deleted from the data analysis.

Two firings were conducted using the 0.375 in. thick steel acceptor plates with resultant velocities of 5,828 fps and 5,150 fps. These tests yielded a detonation and a deflagration respectively. Establishment of boundary velocities with more statistical validity was not possible due to the insufficient number of allocated tests.

Molten Composition B Acceptor - 1.0 Ounce Fragment

A total of 15 tests were performed using the 1.0 ounce fragment and molten Composition B acceptors. Of these tests, 9 used 0.125 in. acceptor plates and the remainder used 0.375 in. thick acceptor plates. Study of the data in Table 6 reveals that for the 0.125 in. thick acceptor plates the minimum velocity for detonation was 4,090 fps while the maximum velocity without detonation was 4,292 fps. Once again there was an overlapping of these two data points, the difference being 202 fps. It is concluded that this is within the experimental error of the fragment velocity measuring technique. The minimum velocity for detonation with the 0.375 in. thick acceptor plates was 3,587 fps while the maximum velocity without detonation was 3,271 fps.

Solid Composition B Acceptor - 2.0 Ounce Fragment

Nine tests were performed on this phase of the program. Results of these tests are presented in Table 7. The minimum velocity for detonation of a solid Composition B acceptor with a 0.125 in. acceptor plate was 4,339 fps. Maximum fragment velocity without detonation was 4,436 fps. The 97 fps overlap is within the acknowledged limits of experimental error on this program. It was not possible to obtain a minimum velocity for detonation with a 0.375 in. acceptor plate. The 2.0 ounce fragment could not be propelled above 4,357 fps. It is concluded that the maximum velocity without detonation is greater than or equal to 4,357 fps.

Molten Composition B Acceptor - 2.0 Ounce Fragment

Results of the 7 tests performed on this phase of the program are presented in Table 8. The minimum velocity for detonation using a 0.125 in. thick acceptor plate was 3,166 fps while the maximum velocity without detonation was 2,937 fps. No detonations occurred with the 0.375 in. acceptor plate at the maximum attainable fragment velocity of 4,510 fps.

Discussion of Results

Control of Fragment Velocity

The degree of control over fragment velocity attained on this program is evident if one analyzes the curves shown in Figure 9. It is seen from these 4 curves of fragment velocity vs. Lucite thickness that results were reproducible within a velocity range of about 500 fps. The effect of increasing frontal area is readily seen by comparing the maximum velocities of the two 0.5 ounce fragments.

Increasing the frontal dimensions from 0.540 in. square to 0.930 in. square resulted in the maximum velocity rising from 4,000 fps to 7,000 fps. Note that to gain this velocity increase at constant fragment weight, the fragment had to be made thinner. This resulted in fragment break-up when Lucite buffer plate thicknesses less than 0.380 in. were used. Table 11 presents the maximum velocities attainable using the 3 in. diameter x 3 in. long Composition B booster.

Effect of Fragment Mass Per Unit Area

The few inconsistencies in the test results have been previously attributed to the spacial orientation of the fragment at the moment of impact. Further discussion of this concept is warranted. A fragment traveling at a constant velocity is said to possess a finite quantity of kinetic energy. The distribution of this energy across the impact surface is one of parameters that determines whether or not a detonation will occur. Therefore, in order to allow a reasonable comparison of threshold velocity data between the various fragments tested, all data was analyzed by comparing fragment mass per unit area to threshold velocity. One would expect that as the magnitude of the mass per unit area term increases, the threshold velocity level would decrease. This phenomenon does occur and can be seen in the results presented in Figures 13, 14 and 15.

The value of using the concept of fragment mass per unit area instead of fragment mass can be seen if Figure 13 is studied. By design, the first 0.5 ounce fragment tested had the same mass per unit area as the 2.0 ounce fragment, namely 1.68 oz. per sq. in. Minimum velocities for detonation for these two fragments were 4,578 fps and 4,339 fps respectively. A difference of only 239 fps. Similarly, the second 0.5 ounce fragment with a mass per unit area of 0.58 oz. per sq. in. has a higher minimum velocity for detonation, 5,798 fps, as would be expected if the theory held true. If fragment mass was plotted against fragment velocity, the results would have been misleading. For example, the two 0.5 ounce fragments would have threshold levels that differed by 1,220 fps (See Table 9). This is not logical and would have caused an incorrect conclusion to be drawn.

Comparison of Test Results

Analysis of the data presented in Table 10 reveals that the molten Composition B acceptors were more sensitive to fragment impact than the solid Composition B acceptors. This statement is valid for both the 0.125 in. and 0.375 in. thick steel cover plates. The differences in minimum velocity for detonation are significant and can not be attributed to experimental error. Similar differences are found in the maximum velocity without detonation results.

If one now compares the differences in minimum velocity for detonation between the two different acceptor plate thicknesses, it is noted that the thicker plates require higher velocities for detonation. There is only one exception to this statement, the 1.0 ounce fragment with molten acceptor. This exception is attributed to the lack of more data points. It is believed that additional testing would have raised the velocities above those reported.

The use of the 0.375 in. thick steel acceptor plate resulted in inconclusive data for the 0.5 and 2.0 ounce fragments. Fragment break-up was a problem with the 0.5 ounce fragment traveling above 7,068 fps. The 2.0 ounce fragment could not be propelled above 4,510 fps using the booster system established for this program. This resulted in the inability to transfer the required initiation energy through the thick plate and into the solid or molten explosive. Attainment of higher velocities with the 2.0 ounce fragments is possible if a larger diameter booster is used. The l/d ratio of the larger booster must be equal to 1.0. A larger booster was not used since it was not within the scope of this program.

Figure 15 sums up the test program results for those tests which used the 0.125 in. thick acceptor plates. For the three fragments with the mass per unit areas shown, it is seen that the molten acceptors require significantly lower velocities for detonation. The regions to the right of each curve are the detonation zones. Finally, it is seen that the minimum velocity for detonation increases as the fragment mass per unit area decreases for both solid and molten Composition B acceptors.

CONCLUSIONS

As a result of the 85 primary steel fragment impact experiments performed on this program using both molten and solid Composition B acceptors with 0.125 in. thick and 0.375 in. thick steel cover plates, it is possible to conclude the following:

1. An empirical relationship has been established between fragment mass per unit impact area and boundary velocity for most of the cases investigated on this program. The work conducted by previous investigators (References 1 and 2) has been extended to allow for the effects of impact area on boundary velocity.

2. The 3 in. diameter x 3 in. long Composition B fragment launch system can propell 0.25, 0.50, 1.0 and 2.00 ounce steel fragments at maximum velocities of 4,304, 7,068, 6,136 and 4,505 fps respectively.

3. Molten Composition B is significantly more sensitive to fragment impact than solid Composition B.

4 Threshold initiation velocities for both solid and molten Composition B are inversely proportional to fragment mass per unit impact area.

5. The minimum fragment velocity required for detonation increases as the thickness of the cover plate increases.

6. The explosive launching technique used on this program proved to be an effective means of propelling square fragments at high velocities.

RECOMMENDATIONS

It is recommended that implementation of the following items be considered:

(1) Use the data generated on this program to modify the mathematical equation for boundary velocity presented in References 1 and 2 by applying the effect of fragment mass per unit impact area on boundary velocity.

(2) Consider the application of this fragment explosive launch technique as a means of classifying the relative sensitivities of explosives, propellants and pyrotechnic materials to high velocity fragment impact. That is, consider this method as a standard hazards classification technique.

(3) Perform additional tests using a larger booster in order to obtain more complete boundary velocity data for the fragments and cover plate thicknesses tested.

(4) Perform additional tests on molten and solid Composition B in order to increase the statistical validity of the data.

(5) Duplicate this test effort using other solid and molten explosives and propellants at various stages of manufacture.

(6) Establish the boundary velocities for molten and solid TNT. Use TNT as the baseline of comparison for all other hazardous materials.

REFERENCES

1. D. G. McLean and D. S. Allan, "An Experimental Program to Determine the Sensitivity of Explosive Materials to Impact by Regular Fragments," Arthur D. Little, Inc., Report No. 64514.

2. R. M. Rindner, "Establishment of Safety Design Criteria for Use in Engineering of Explosive Facilities and Operations", Report No. 2, Detonation by Fragment Impact, May 1959, Picatinny Arsenal Report DB - TR: 6 - 59.

TABLE 1 - Combinations of Parameters Tested

Frag. Wt. (oz)	Fragment Dimension (in x in x in)	Frag. Wt/A (oz/in^2)	Acceptor Plate Thk. (in)	Acceptor Material	No. Of Tests
.25	.375 x .375 x .375	1.79	.125	Solid	2
.5	.375 x .540 x .540	1.68	.125	Solid	16
.5	.125 x .930 x .930	0.58	.125	Solid	10
.5	.125 x .930 x .930	0.58	.375	Solid	3
.5	.125 x .930 x .930	0.58	.125	Molten	6
.5	.125 x .930 x .930	0.58	.375	Molten	3
1.0	.250 x .930 x .930	1.16	.125	Solid	12
1.0	.250 x .930 x .930	1.16	.375	Solid	2
1.0	.250 x .930 x .930	1.16	.125	Molten	9
1.0	.250 x .930 x .930	1.16	.375	Molten	6
2.0	.375 x 1.09 x 1.09	1.68	.125	Solid	7
2.0	.375 x 1.09 x 1.09	1.68	.375	Solid	2
2.0	.375 x 1.09 x 1.09	1.68	.125	Molten	5
2.0	.375 x 1.09 x 1.09	1.68	.375	Molten	2

TABLE 2 - Results of Tests With 0.5 Ounce Fragments - Solid Acceptors

Fragment - .375 in x .540 in x .540 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
1	0.040	.375	4,055	none	Calibration Test	N.A.
2	1.000	.125	2,575	none	Calibration Test	N.A.
3	1.875	.125	1,704	none	Calibration Test	N.A.
4	0.040	.125	8,209	8 x 8 x 1	Detonation-frag. broke-up, not valid point	N.A
5	0.500	.125	3,196	8 x 8 x .75	Deflagration	-
6	0.250	.125	3,545	8 x 8 x 1	Deflagration	-
7	0.125	.125	3,716	8 x 8 x 1	Deflagration	-
8	0.065	.125	3,959	8 x 8 x 1	Deflagration	-
9	0.040	.125	3,984	8 x 8 x 1	Deflagration	-
10	0.125	.125	3,937	8 x 8 x 1	Deflagration	-
11	0.040	.125	4,472	8 x 8 x 1	Deflagration	-
12	0.065	.125	3,948	8 x 8 x 1	No Reaction	-

TABLE 2 (Con't.) - Results of Tests With 0.5 Ounce Fragments - Solid Acceptors

Fragment - .375 in x .540 in x .540 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
13	0.040	.125	4,742	8 x 8 x 1	Deflagration	-
14	0.065	.125	4,578	8 x 8 x 1	Detonation	+
15	0.040	.125	4,748	8 x 8 x 1	Detonation	+
16	0.040	.125	4,534	6 x 6 x 2	Deflagration	-

Note: (1) Firings 1-9, performed using 3 in. dia. x 3 in. long booster
(2) Firings 10 and 11 performed using 3 in. dia. x 4 in. long booster
(3) Firings 12 and 15 performed using 3 in. dia. x 5 in. long booster
(4) Firing 13 performed using 3 in. dia. x 6 in. long booster
(5) Firing 14 performed using 3 in. dia. x 8 in. long booster

* + indicates detonation
\- indicates no reaction or deflagration

TABLE 3 - Results of Tests With 0.5 Ounce Fragments - Solid Acceptors

Fragment - .125 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
17	0.038	.125	8,834	6 x 6 x 2	Detonation-frag. broke-up, not valid point	N.A.
18	0.125	.125	8,530	6 x 6 x 2	Detonation-frag. broke-up, not valid point	N.A.
19	0.250	.125	8,053	6 x 6 x 2	Detonation-frag. broke-up, not valid point	N.A.
20	0.375	.125	6,508	6 x 6 x 2	Detonation	+
21	0.750	.125	5,651	4 x 4 x 4.5	Missed Target	N.A.
22	0.750	.125	4,479	6 x 6 x 2	Missed Target	N.A.
23	0.750	.125	5,798	6 x 6 x 2	Detonation	+
24	1.500	.125	3,909	6 x 6 x 2	Deflagration	-
25	1.000	.125	5,102	6 x 6 x 2	Deflagration	-
26	1.000	.125	5,206	6 x 6 x 2	Deflagration	-

TABLE 3 (Con't.) - Results of Tests With 0.5 Ounce Fragments - Solid Acceptors

Fragment - .125 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
27	0.750	.375	5,725	6 x 6 x 2	Deflagration	-
28	0.375	.375	7,068	6 x 6 x 2	Deflagration	-
29	0.125	.375	9,462	6 x 6 x 2	Detonation-frag. broke-up, not valid point	N.A.

* + indicates detonation
- indicates no reaction or deflagration

TABLE 4 - Results of Tests With 0.5 Ounce Fragments - Molten Acceptors

Fragment - .125 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
30	0.750	.125	5,645	6 x 6 x 1.75	Detonation	+
31	0.375	.125	6,630	6 x 6 x 1.75	Detonation	+
32	1.000	.125	4,945	6 x 6 x 1.75	Missed Target	N.A.
33	1.000	.125	5,064	6 x 6 x 1.75	Missed Target	N.A.
34	1.000	.125	5,155	8 x 8 x .75	Detonation	+
35	1.250	.125	4,626	8 x 8 x .75	Deflagration	-
36	0.375	.375	7,047	6 x 6 x 1.75	Detonation	+
37	0.625	.375	7,516	6 x 6 x 1.75	Detonation-frag. broke-up, not valid point	N.A.
38	1.250	.375	4,602	6 x 6 x 1.75	No Reaction	-

* + indicates detonation
- indicates no reaction or deflagration

TABLE 5 - Results of Tests With 1.0 Ounce Fragments - Solid Acceptors

Fragment - .250 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
39	0.040	.125	5,988	8 x 8 x 1	Detonation	+
40	0.040	.125	5,893	8 x 8 x 1	Detonation	+
41	0.040	.125	6,102	6 x 6 x 2	Detonation	+
42	0.038	.125	6,136	6 x 6 x 2	Detonation	+
43	0.250	.125	5,418	6 x 6 x 2	Detonation	+
44	0.500	.125	4,291	6 x 6 x 2	Detonation	+
45	1.000	.125	3,683	6 x 6 x 2	Deflagration	-
46	0.750	.125	2,704	6 x 6 x 2	Deflagration	-
47	0.750	.125	2,818	6 x 6 x 2	Deflagration	-
48	0.750	.125	3,745	6 x 6 x 2	Deflagration	-
49	0.500	.125	4,495	6 x 6 x 2	Deflagration	-

TABLE 5 (Con't.) - Results of Tests With 1.0 Ounce Fragments - Solid Acceptors

Fragment - .250 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
50	0.500	.125	4,518	6 x 6 x 2	No Reaction	-
51	0.040	.375	5,828	6 x 6 x 1.5	Detonation	+
52	0.250	.375	5,150	6 x 6 x 2	Deflagration	-

Note: Run 44, fragment impacted on its thin edge. Not valid for comparison.

* + indicates detonation
   - indicates no reaction or deflagration

TABLE 6 - Results of Tests With 1.0 Ounce Fragments - Molten Acceptors

Fragment - .250 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
53	0.500	.125	4,602	8 x 8 x .75	Deflagration	-
54	0.250	.125	5,231	8 x 8 x .75	Deflagration	-
55	0.250	.125	4,967	6 x 6 x 1.75	Detonation	+
56	1.000	.125	3,741	6 x 6 x 1.75	Deflagration	-
57	0.500	.125	4,500**	6 x 6 x 1.75	Detonation	+
58	0.750	.125	4,090	6 x 6 x 1.75	Detonation	+
59	1.000	.125	3,464	6 x 6 x 1.75	Detonation	+
60	1.250	.125	3,282	6 x 6 x 1.75	Deflagration	-
61	0.500	.125	4,292	6 x 6 x 1.75	Deflagration	-
62	0.040	.375	5,853	6 x 6 x 1.75	Detonation	+
63	0.125	.375	5,295	6 x 6 x 1.75	Detonation	+
64	0.250	.375	5,090	6 x 6 x 1.75	Detonation	+

TABLE 6 (Con't.) - Results of Tests With 1.0 Ounce Fragments - Molten Acceptors

Fragment - .250 in x .930 in x .930 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
65	0.500	.375	4,666	6 x 6 x 1.75	Detonation	+
66	1.000	.375	3,587	6 x 6 x 1.75	Detonation	+
67	1.250	.375	3,271	6 x 6 x 1.75	No Reaction	-

* + indicates detonation
 - indicates no reaction or deflagration

** Camera Malfunction, velocity estimated from Figure 8

Note: (1) Runs 53 and 54 were not valid for comparison purposes due to difference in acceptor thickness.

(2) Run 59 fragment impacted on edge. Not valid for comparison.

TABLE 7 - Results of Tests With 2.0 Ounce Fragments - Solid Acceptors

Fragment - .375 in x 1.09 in x 1.09 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
68	0.040	.125	4,436	6 x 6 x 2	Deflagration	-
69	0.040	.125	4,452	6 x 6 x 2	Detonation	+
70	1.000	.125	2,834	6 x 6 x 2	Deflagration	-
71	0.500	.125	3,553	6 x 6 x 2	Deflagration	-
72	0.250	.125	3,984	6 x 6 x 2	Deflagration	-
73	0.125	.125	4,339	6 x 6 x 2.25	Detonation	+
74	0.038	.125	4,372	6 x 6 x 2	Detonation	+
75	0.040	.375	4,357	6 x 6 x 2	Deflagration	-
76	0.040	.375	4,334	6 x 6 x 2	Deflagration	-

* + indicates detonation
  \- indicates no reaction or deflagration

TABLE 8 - Results of Tests With 2.0 Ounce Fragments - Molten Acceptors

Fragment - .375 in x 1.09 in x 1.09 in

Test No.	Lucite Thickness (in)	Acceptor Plate Thickness (in)	Fragment Velocity (fps)	Acceptor Dimensions (in)	Remarks	Result*
77	0.040	.125	4,464	6 x 6 x 1.75	Detonation	+
78	0.500	.125	3,305	6 x 6 x 1.75	Detonation	+
79	0.750	.125	3,166	6 x 6 x 1.75	Detonation	+
80	1.000	.125	2,771	6 x 6 x 1.75	No Reaction	-
81	0.875	.125	2,937	6 x 6 x 1.75	Deflagration	-
82	0.040	.375	4,510	6 x 6 x 1.75	Deflagration	-
83	0.040	.375	4,505	6 x 6 x 1.75	Deflagration	-

* + indicates detonation
- indicates no reaction or deflagration

TABLE 9 - Comparison of Velocity Data

Fragment Weight (oz)	Fragment Wt/A (oz/in^2)	Acceptor Plate Thk. (in)	Acceptor Condition (solid/molten)	Min. Velocity for Detonation (fps)	Max. Velocity Without Detonation (fps)
0.5	1.68	.125	solid	4,578	4,742
0.5	0.58	.125	solid	5,798	5,206
0.5	0.58	.375	solid	*	$\geq$ 7,068
0.5	0.58	.125	molten	5,155	4,626
0.5	0.58	.375	molten	7,047	4,602
1.0	1.16	.125	solid	5,418	4,518
1.0	1.16	.375	solid	5,828	5,150
1.0	1.16	.125	molten	4,090	4,292
1.0	1.16	.375	molten	3,587	3,271
2.0	1.68	.125	solid	4,339	4,436
2.0	1.68	.375	solid	-	$\geq$ 4,357**
2.0	1.68	.125	molten	3,166	2,937
2.0	1.68	.375	molten	-	$\geq$ 4,510**

* Could not achieve detonation level without fragment break-up

** Maximum velocity attainable with the 3 in. dia. x 3 in. long booster

TABLE 10 - Summary of Fragment Impact Test Results

Fragment Weight (oz)	Acceptor Plate Thk. (in)	Min. Vel. for Det.		Max. Vel. Without Det.	
		Solid (fps)	Molten (fps)	Solid (fps)	Molten (fps)
0.5	.125	5,798	5,155	5,206	4,626
1.0	.125	5,418	4,090	4,518	4,292
2.0	.125	4,339	3,166	4,436	2,937
0.5	.375	*	7,047	≥ 7,068	4,602
1.0	.375	5,828	3,587	5,150	3,271
2.0	.375	-	-	≥ 4,357**	≥ 4,510**

* Could not achieve detonation level without fragment break-up
** Maximum velocity attainable with the 3 in. dia. x 3 in. long booster

TABLE 11 - Summary of Maximum Fragment Velocities

Fragment Wt. (oz)	Fragment Dimension (in x in x in)	Maximum Fragment Velocity (fps)
0.25	.375 x .375 x .375	4,304
0.50	.375 x .540 x .540	4,055
0.50	.125 x .930 x .930	7,068
1.00	.250 x .930 x .930	6,136
2.00	.375 x 1.09 x 1.09	4,505

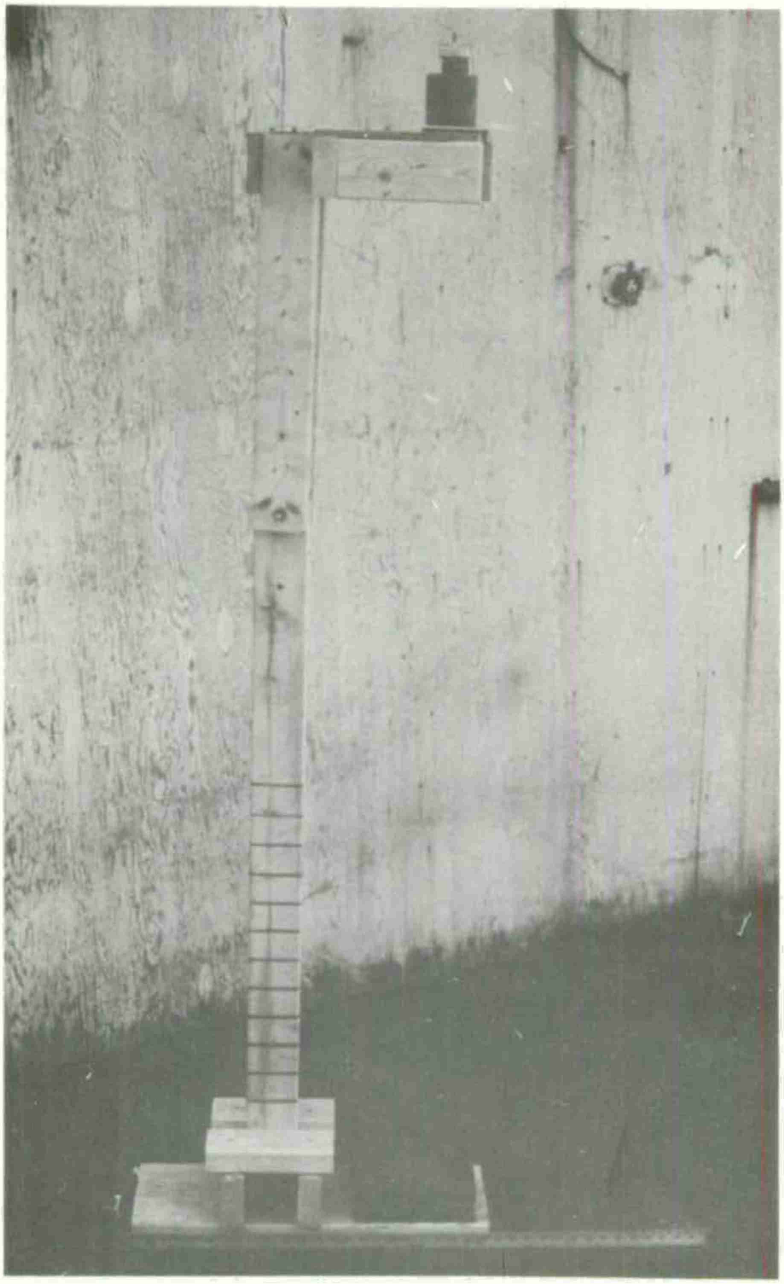

Fig 1 Photo of experimental set-up

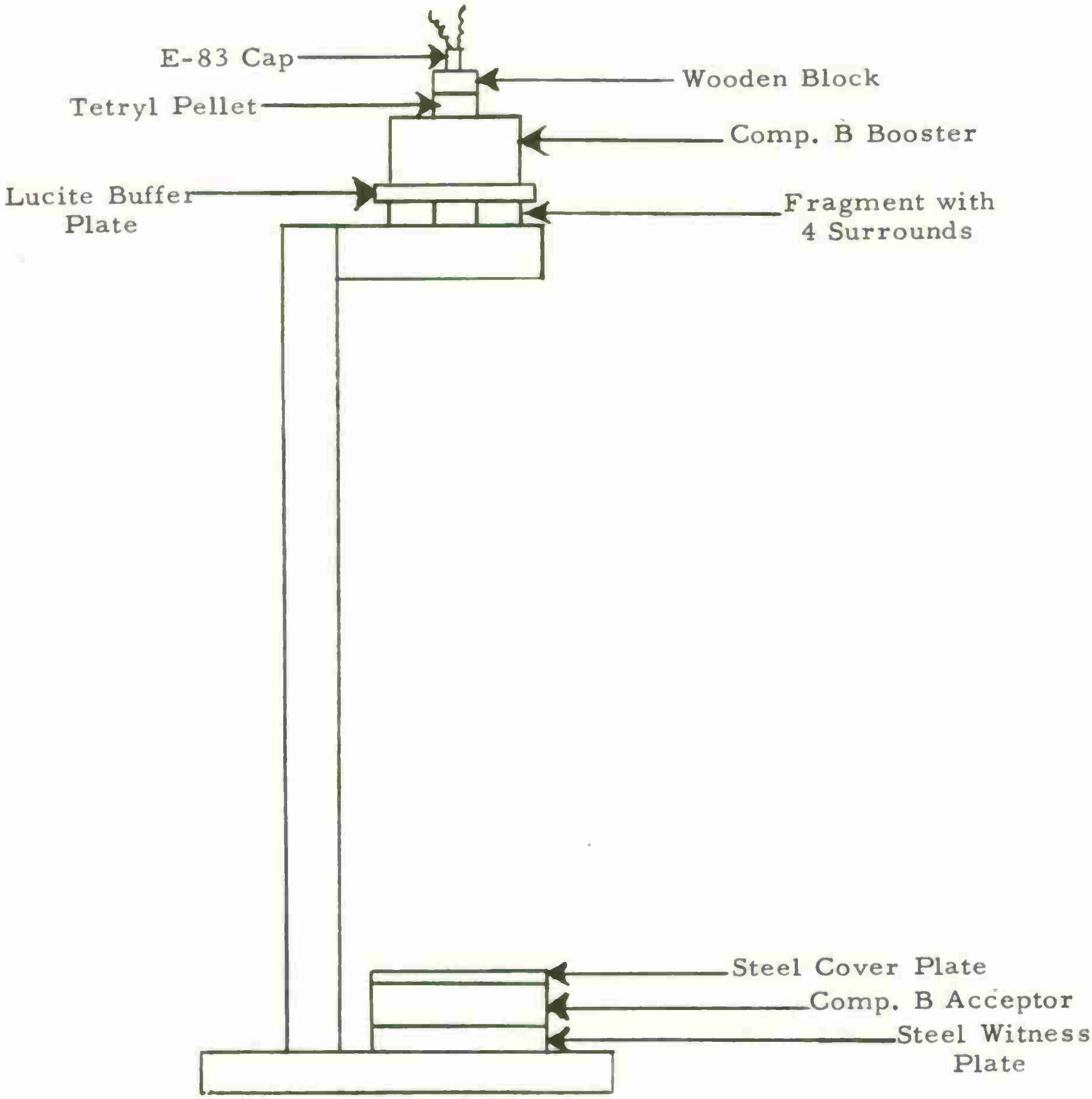

Fig 2 Schematic of experimental set-up

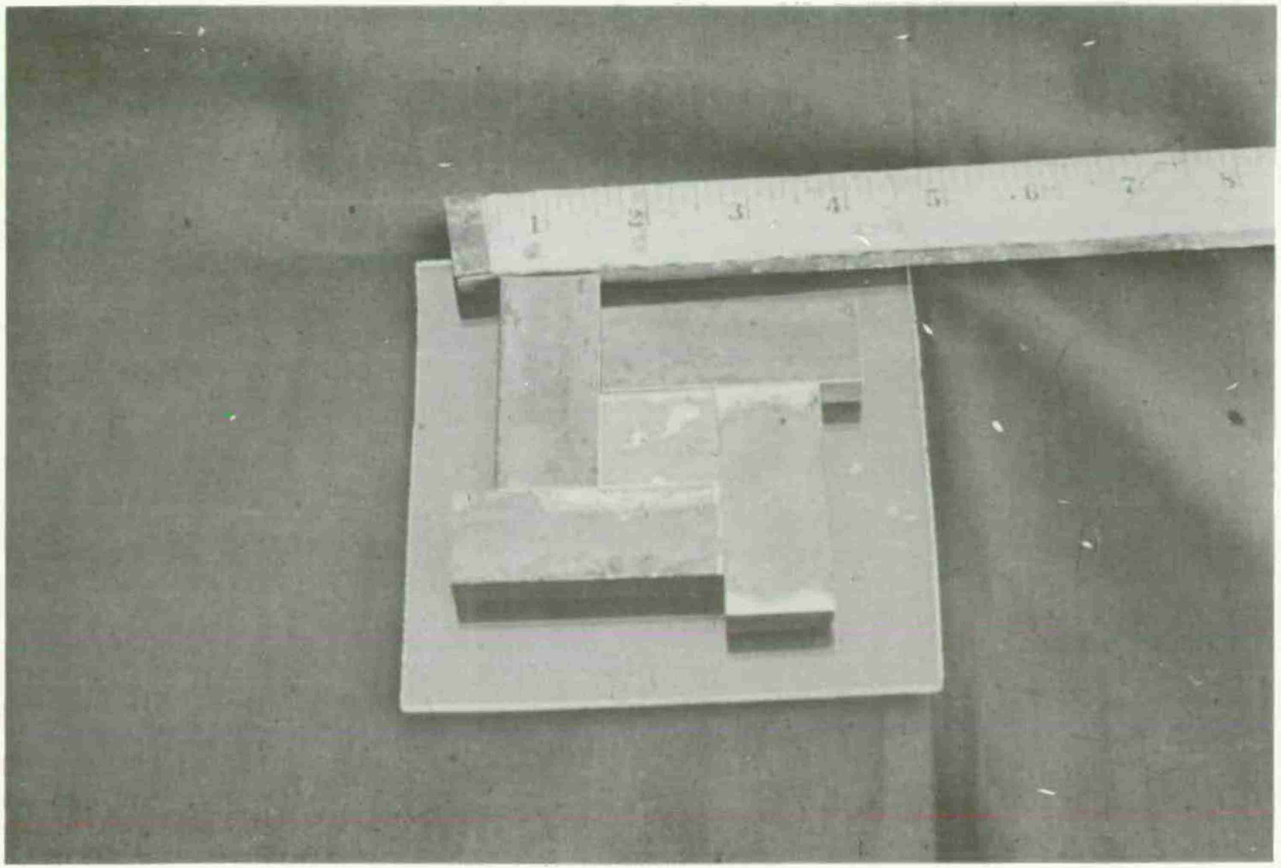

Fig 3 Photo of 2.0 ounce steel fragment, 4 surrounds and lucite buffer plate

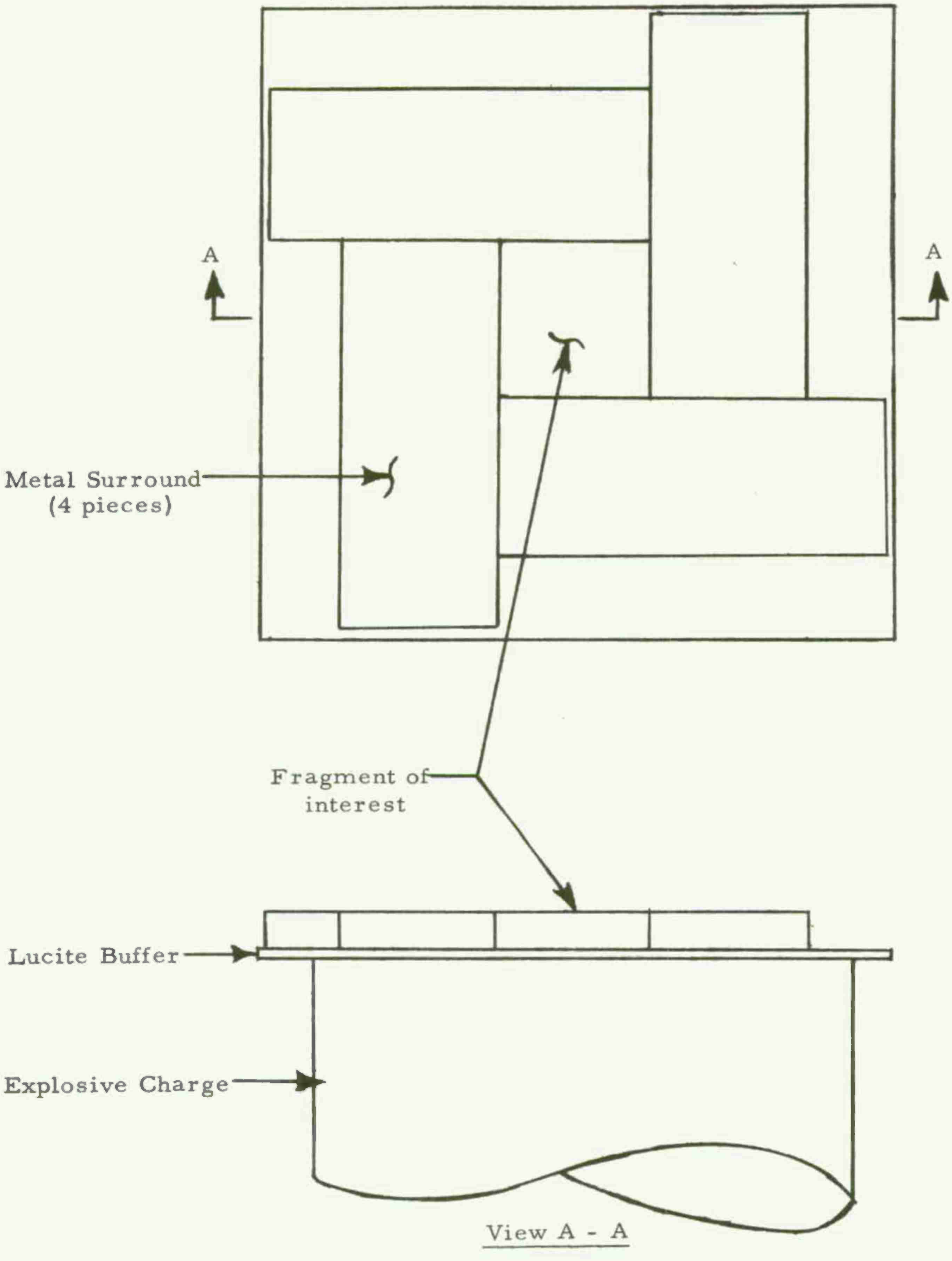

Fig 4 **Fragment propulsion system**

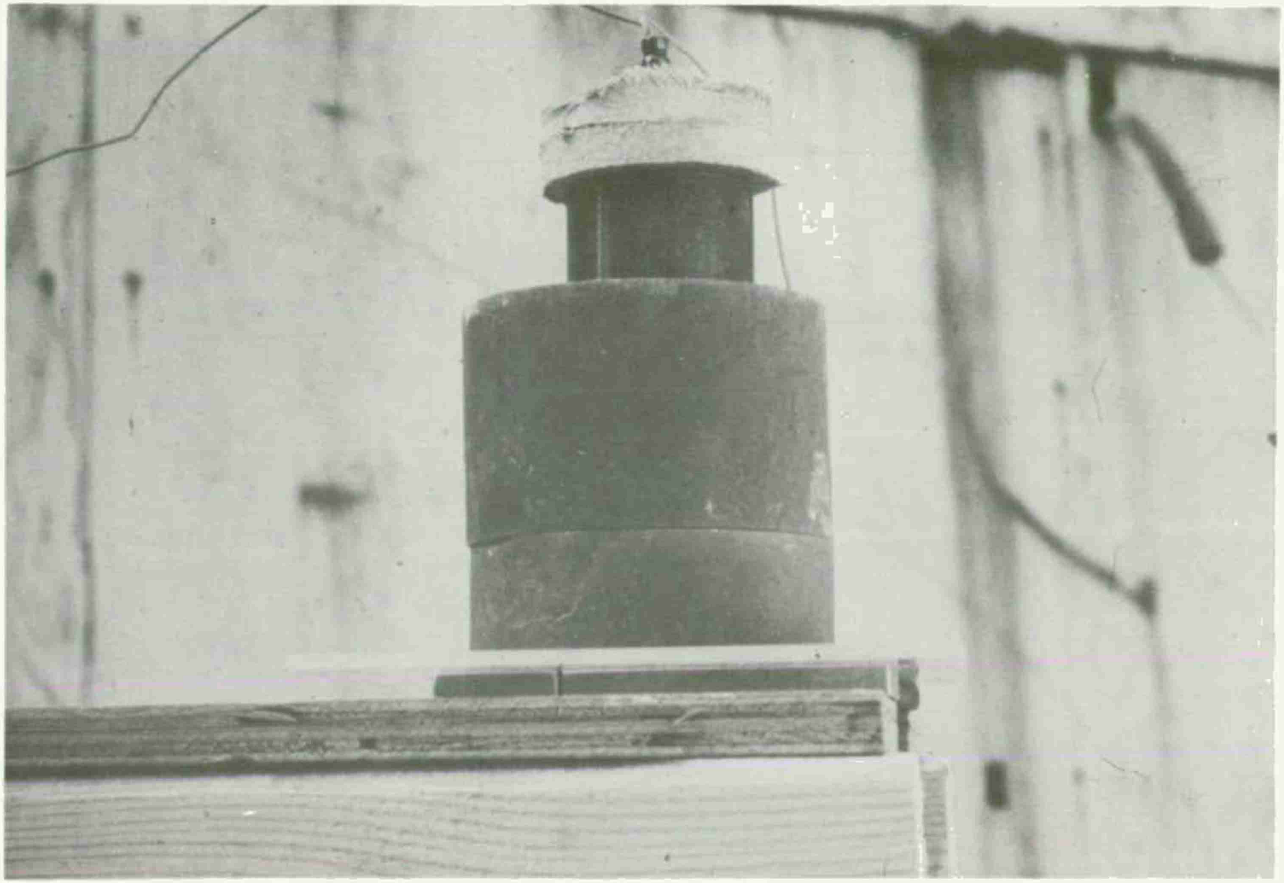

Fig 5 Composition B booster configuration

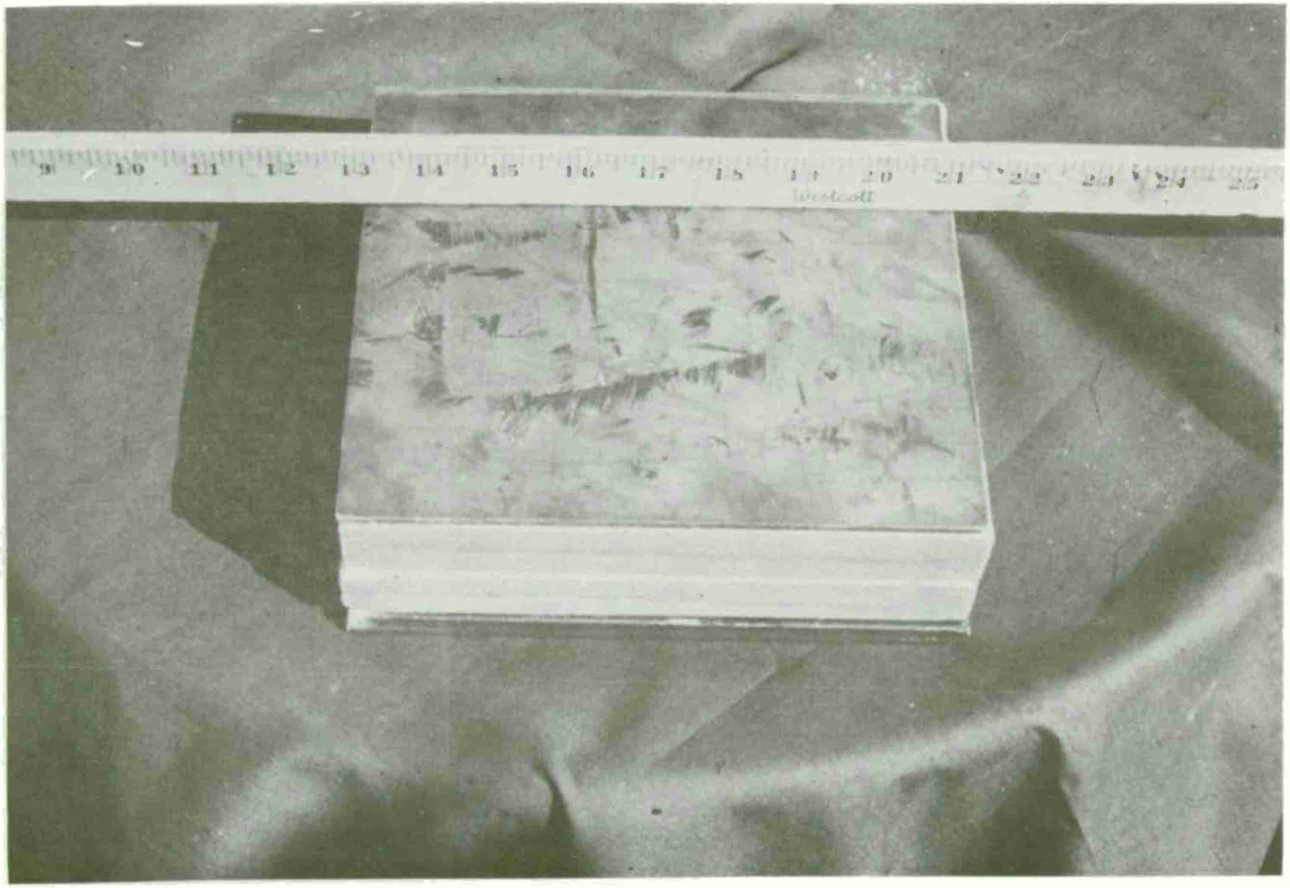

Fig 6 Solid Composition B acceptor charge

Fig 7 Molten Composition B acceptor charge

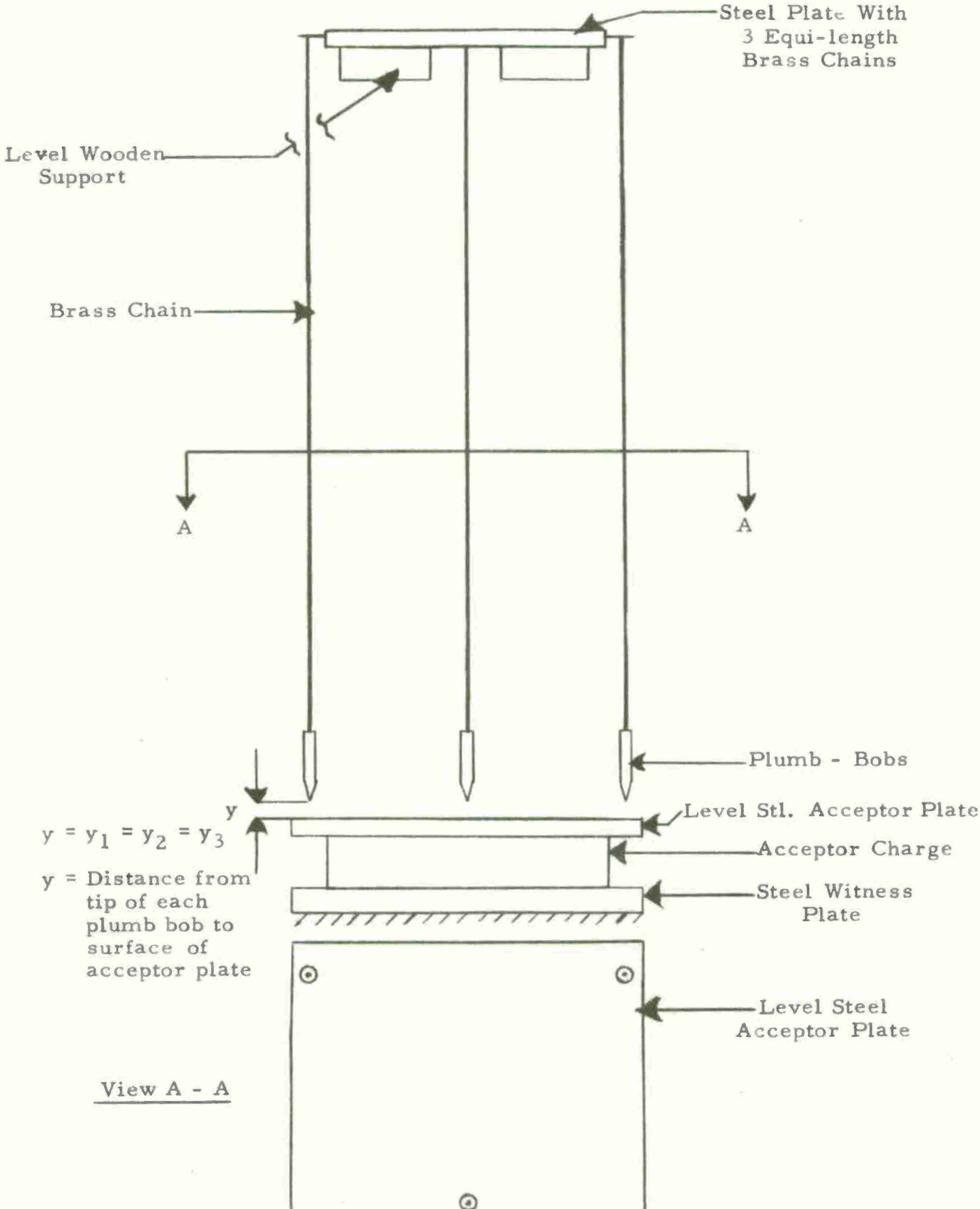

Fig 8 Fragment aiming technique

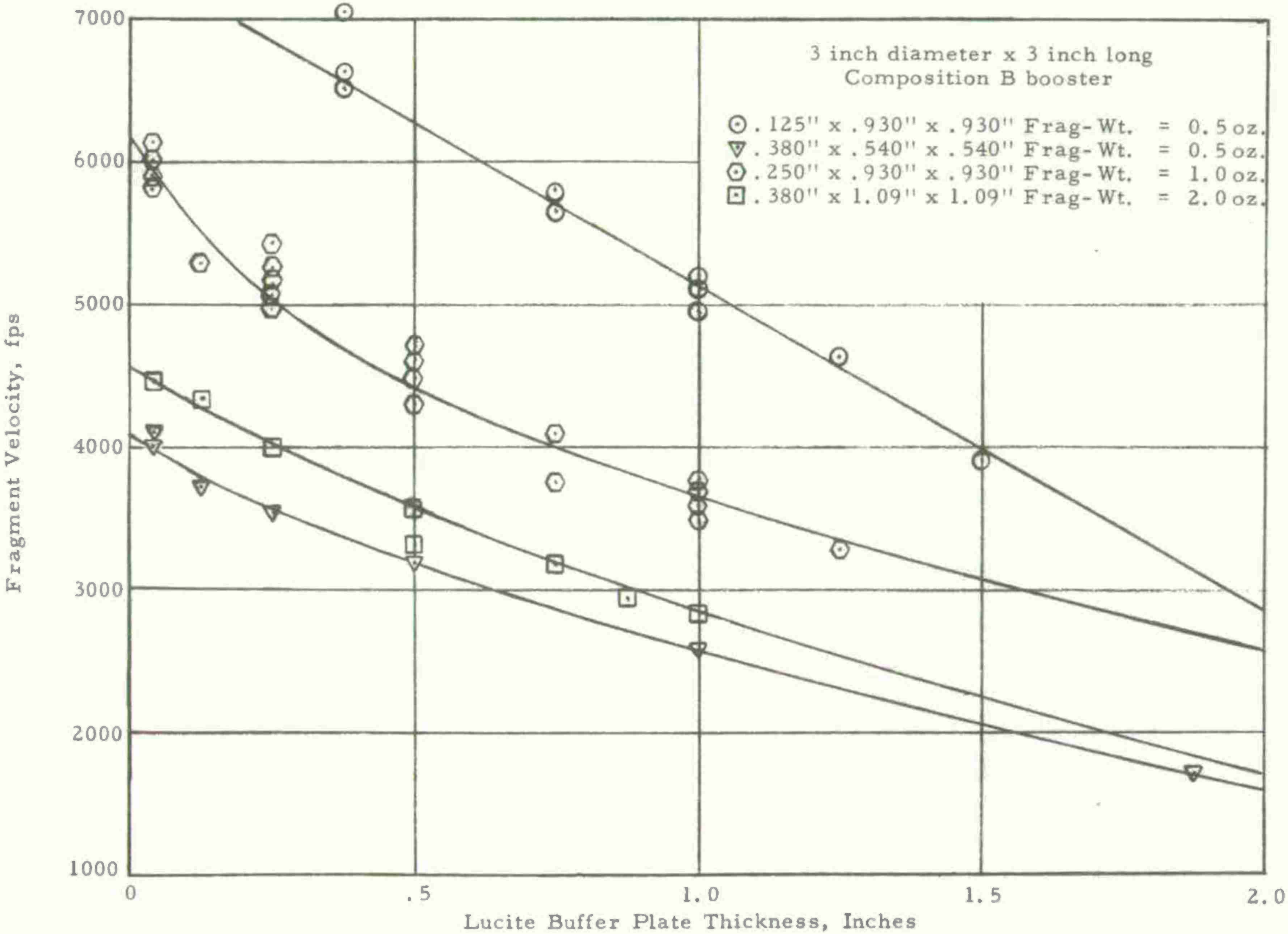

Fig 9 Fragment velocity vs. lucite thickness

Fig 10 Post-run condition of typical witness plate, cover plate and fragment after a negative test result

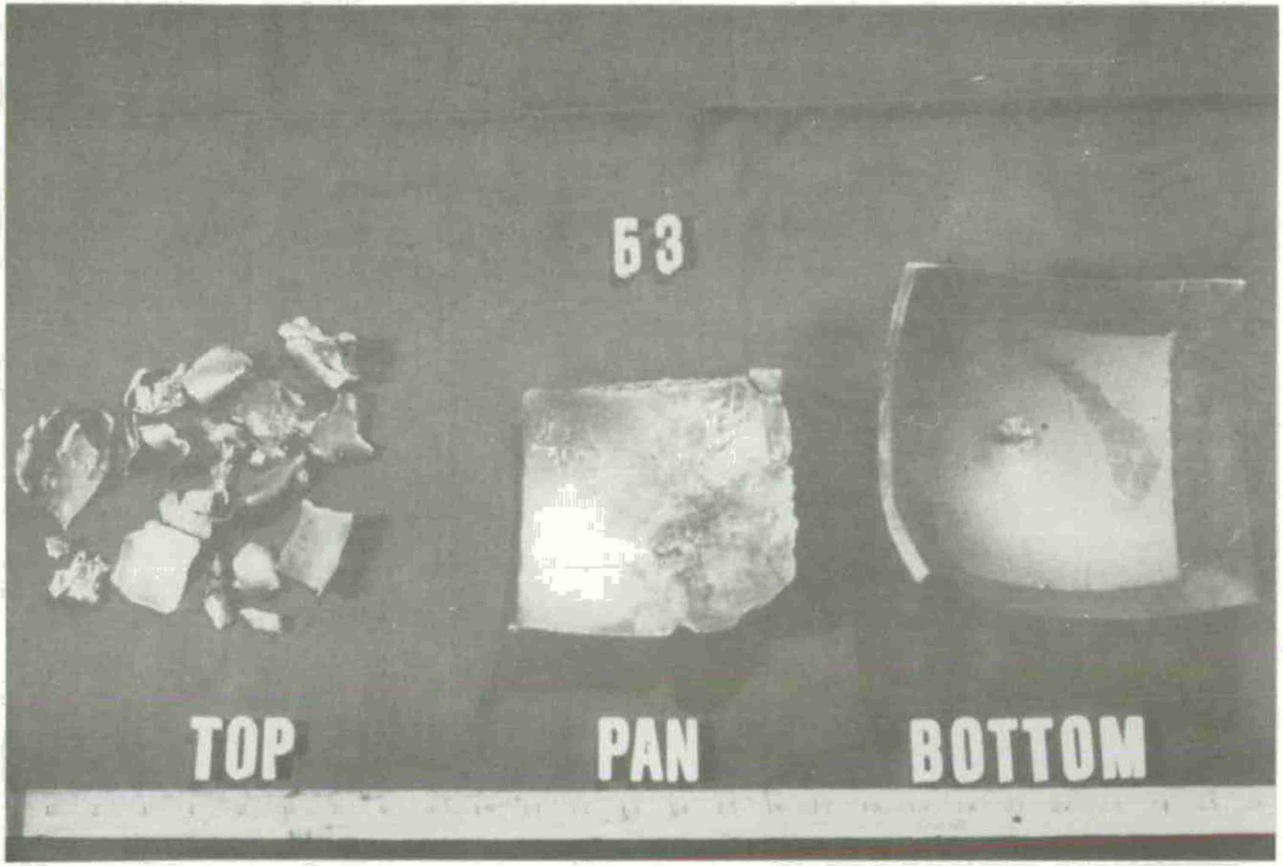

Fig 11 Post-run condition of steel cover plate and witness plate after a low order detonation

Fig 12 Post-run condition of witness plate after a high order detonation

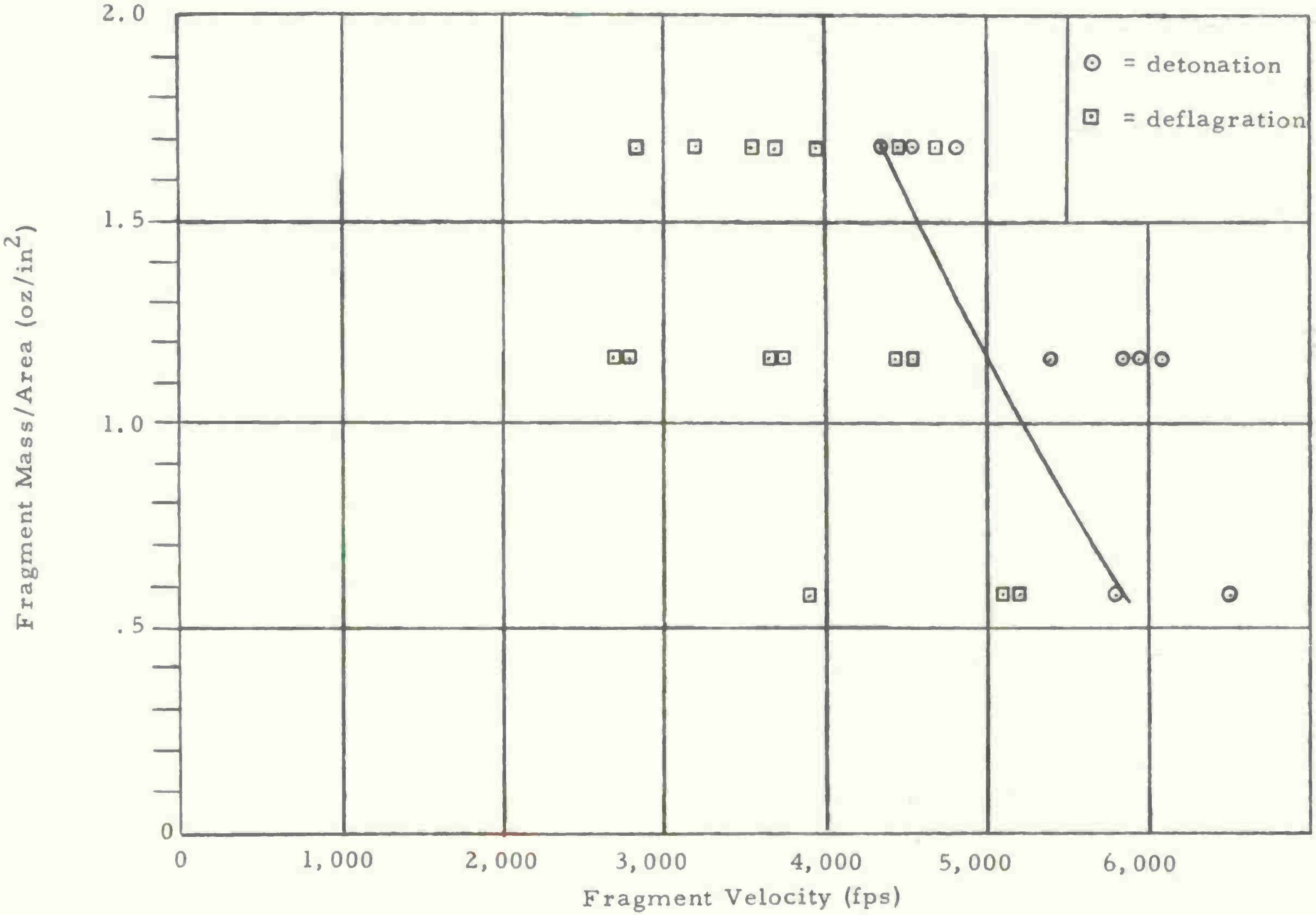

Fig 13 Plot of test results for solid Composition B with 0.125 inch thick acceptor plate

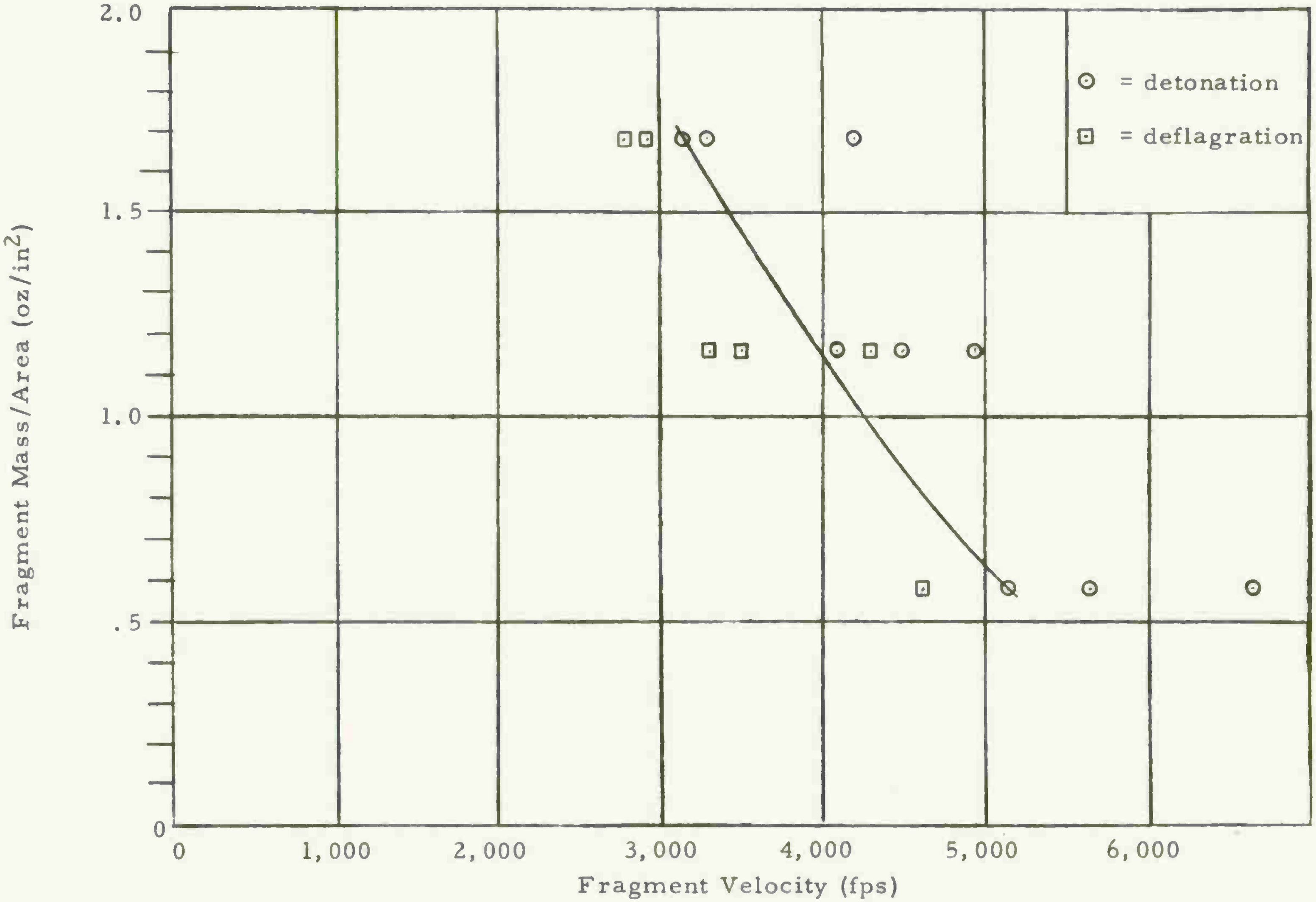

Fig 14 Plot of test results for molten Composition B with 0. 125 inch thick acceptor plate

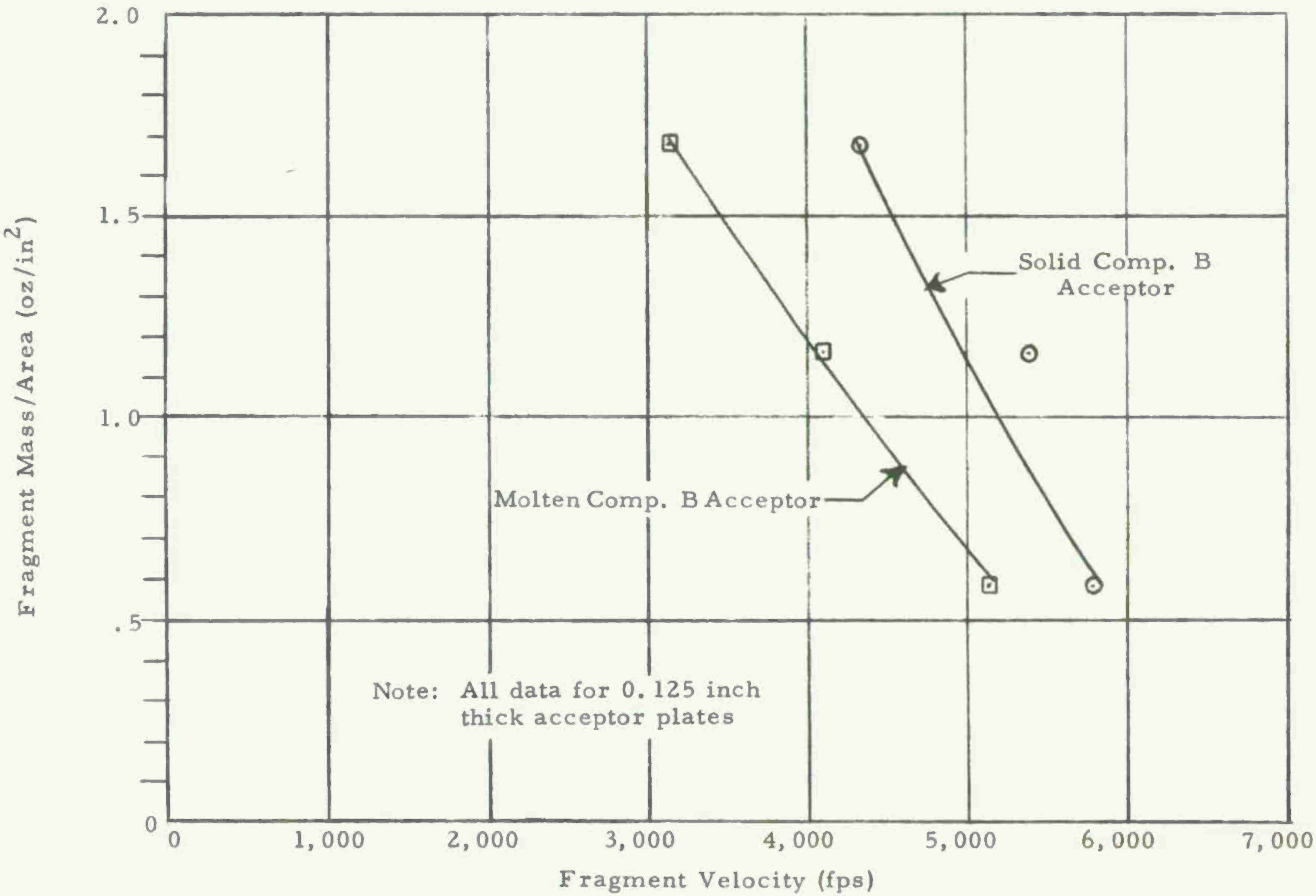

Fig 15 Comparison of minimum velocity for detonation of molten and solid Composition B as a function of fragment mass per unit area

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